

SUMMARY

[0005] In view of the foregoing, it is an objective of the present disclosure to provide a method for attaining good global and local uniformity in etched carbon-based films. These and/or other objectives may be provided by the following aspects of the disclosure.

[0006] An aspect of the disclosure relates to a cyclic etch method for etching a carbon-based film, the method includes:

- providing a substrate comprising the carbon-based film;

- exposing a first exposed surface of the carbon-based film to a first process gas that includes a first plasma, thereby forming a first activated layer starting from the first exposed surface of the carbon-based film to a first depth below the first exposed surface of the carbon-based film;

- exposing the first activated layer to a second process gas comprising a second plasma, thereby removing the first activated layer and forming, as a first carbonized layer, a second exposed surface of the carbon-based film, wherein the removal of the first activated layer etches the carbon-based film by an amount corresponding to the first depth below the first exposed surface of the carbon-based film to form the second exposed surface of the carbon-based film, wherein the second process gas is a non-activating inert gas;

- exposing the second exposed surface of the carbon-based film to the first process gas that includes the first plasma, thereby forming a second activated layer starting from the second exposed surface of the carbon-based film to a second depth below the second exposed surface of the carbon-based film; and

- exposing the second activated layer to the second process gas comprising the second plasma, thereby removing the second activated layer and forming, as a second carbonized layer, a third exposed surface of the carbon-based film, wherein the removal of the second activated layer etches the carbon-based film by an amount corresponding to the second depth below the second exposed surface of the carbon-based film to form the third exposed surface of the carbon-based film,

wherein a frequency power of the first plasma is greater than a frequency power of the second plasma,

wherein a first duration for exposing the first and second activated layers to the second process gas is longer than a second duration for exposing the first and second exposed surfaces of the carbon-based film to the first process gas.

[0007] In one embodiment, wherein the first process gas includes a first plasma formed by plasma-exciting a process gas consisting of O₂ gas.

[0008] In one embodiment, the first process gas includes a first plasma formed by plasma-exciting a process gas consisting of O₂ gas and an inert gas.

[0009] In one embodiment, the first process gas includes a first plasma formed by plasma-exciting a process gas comprising O₂ gas and Ar gas.

[0010] In one embodiment, the second process gas includes a second plasma formed by plasma-exciting a process gas consisting of Ar gas.

[0011] In one embodiment, the carbon-based film comprises at least one of a hydrocarbon polymer and an amorphous hydrogenated carbon.

[0012] In one embodiment, the carbon-based film comprises carbon and hydrogen, and the carbonized layer is at least substantially free of hydrogen.

[0013] In one embodiment, a patterned mask layer overlies the carbon-based film.

[0014] In one embodiment, the patterned mask layer includes: (i) an anti-reflective coating comprising silicon, wherein the anti-reflective coating is on the carbon-based film; and (ii) a photoresist layer on the anti-reflective coating.

[0015] In one embodiment, the formation of the activated layer and the formation of the carbonized layer are self-limiting processes.

[0016] In one embodiment, the carbon-based film comprises carbon and hydrogen, the method further includes monitoring light emission from by-products released from the

Claims

1. A cyclic etch method for etching a carbon-based film, the method comprising:

providing a substrate comprising the carbon-based film;

exposing the first exposed surface of the carbon-based film to a first process gas that includes a first plasma, thereby forming a first activated layer starting from the first exposed surface of the carbon-based film to a first depth below the first exposed surface of the carbon-based film;

exposing the first activated layer to a second process gas comprising a second plasma, thereby removing the first activated layer and forming, as a first carbonized layer, a second exposed surface of the carbon-based film, wherein the removal of the first activated layer etches the carbon-based film by an amount corresponding to the first depth below the first exposed surface of the carbon-based film to form the second exposed surface of the carbon-based film, wherein the second process gas is a non-activating inert gas;

exposing the second exposed surface of the carbon-based film to the first process gas that includes the first plasma, thereby forming a second activated layer starting from the second exposed surface of the carbon-based film to a second depth below the second exposed surface of the carbon-based film; and

exposing the second activated layer to the second process gas comprising the second plasma, thereby removing the second activated layer and forming, as a second carbonized layer, a third exposed surface of the carbon-based film, wherein the removal of the second activated layer etches the carbon-based film by an amount corresponding to the second depth below the second exposed surface of the carbon-based film to form the third exposed surface of the carbon-based film,

wherein a frequency power of the first plasma is greater than a frequency power of the second plasma,

wherein a first duration for exposing the first and second activated layers to the second process gas is longer than a second duration for exposing the first and second exposed surfaces of the carbon-based film to the first process gas.

2. The method of claim 1, wherein the first process gas comprises the first plasma formed by plasma-exciting a process gas consisting of O₂ gas.

3. The method of claim 1, wherein the first process gas comprises the first plasma formed by plasma-exciting a process gas consisting of O₂ gas and an inert gas.

4. The method of claim 1, wherein the first process gas comprises the first plasma formed by plasma-exciting a process gas comprising O₂ gas and Ar gas.

5. The method of claim 1, wherein the second process gas comprises the second plasma formed by plasma-exciting a process gas consisting of Ar gas.

6. The method of claim 1, wherein the carbon-based film comprises at least one of a hydrocarbon polymer and an amorphous hydrogenated carbon.

7. The method of claim 1, wherein the carbon-based film comprises carbon and hydrogen, and the first and second carbonized layer are depleted of hydrogen relative to the carbon-based film of the substrate.

8. The method of claim 1, wherein a patterned mask layer overlies the carbon-based film.

9. The method of claim 8, wherein the patterned mask layer comprises:
an anti-reflective coating comprising silicon, wherein the anti-reflective coating is on the carbon-based film; and
a photoresist layer on the anti-reflective coating.

10. The method of claim 1, wherein the formation of the first and second activated layers and the formation of the first and second carbonized layer are self-limiting processes.

11. The method of claim 1, wherein the carbon-based film comprises carbon and hydrogen, the method further comprising:
monitoring light emission from by-products released from the carbon-based film to determine properties of the first and second carbonized layers, the first and second activated layers, or both the first and second carbonized layers and the first and second activated layers.

12. The method of claim 11, wherein the properties of the first and second carbonized layers include a thickness of the first and second carbonized layers.

13. The method of claim 11, wherein the properties of the first and second activated layers include a thickness of the first and second activated layers.

14. The method of claim 1, further comprising exposing the first and second activated layers to a silylating agent thereby adding silicon to the first and second activated layers.

15. The method of claim 14, wherein the silylating agent comprises hexamethyldisilazane.

16. The method of claim 1, further comprising exposing the first and second carbonized layers to a silylating agent thereby adding silicon to the first and second carbonized layers.

17. The method of claim 16, wherein the silylating agent comprises hexamethyldisilazane.

18. The method of claim 1, further comprising exposing the carbon-based film to a continuous plasma to remove the carbon-based film by a non-self-limiting process, wherein the continuous plasma is formed by plasma-exciting a process gas comprising O₂ gas and Ar gas.

19. The method of claim 18, further comprising varying relative amounts of O₂ and Ar gas in the continuous plasma.

20. The method of claim 1, wherein the first duration is in a range from 0.5 seconds to 10 seconds, and the second duration is in the range of 0.5 seconds to 10 seconds.

21. The method of claim 20, wherein a sum of the first duration and the second duration is less than or equal to 20 seconds.

22. The method of claim 1, wherein the first duration for exposing the first and second activated layers to the second process gas is 1.5 to 4 times longer than the second duration for exposing the first and second exposed surfaces of the carbon-based film to the first process gas.